Primary Settling Tanks in State of the Art Wastewater Treatment

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Abstract

The paper provides an overview on the latest results in the field of primary settling in terms of scientific research and design. In state of the art wastewater treatment primary settling tanks (PSTs) are considered as integral part of biological wastewater treamtent, sludge treatment and biogas production, consequently essencial part of the energetics of large wastewater treatment plants. Strongly focusing on process oriented analysis, design and operation of PSTs, over the previous few years (2013, 2014 and 2015) at a huge number of PSTs "in situ" full scale measurements were carried out. Removal efficiency, settling properties of primary sludge, internal flow structures within PSTs and their impact on performance were ivestigated. The paper presents the basic design goals and operation principles of PSTs, the results of full scale measurements, which also served as input data for the new edition of the German design guidline A 131 (DWA 2015). Also CFD investigations calibrated and validated based on full scale measurements are shown, which highlight some interesting details how geometry design affects PST performance.

Keywords: Wastewater treatment, primary settling tanks, computational fluid dynamics, design, biodegradable carbon, suspended solids

Introduction

As an integral part of the design process of biological wastewater treatment plants, the German design guideline A 131 (DWA 2015) for dimensioning single-stage activated sludge plants requires a measurement or estimation of the performance of PSTs especially with respect to the elimination of suspended solids and particulate COD. The detailed consideration of the primary clarification as an integral part gives the opportunity not only to optimise the wastewater treatment process concerning maximum nitrogen elimination by providing a sufficient amount of biodegradable COD for denitrification or minimising the required volume for nitrogen elimination in the biological treatment step. But it also allows to optimise the energy situation of the plant by removing as much particulate COD in the PST as possible without impairing the biological nitrogen removal.

Strongly focusing on process oriented analysis, design and operation of PSTs, over the previous few years (2013, 2014 and 2015) at a huge number of PSTs "in situ" full scale measurements were carried out. Removal efficiency, settling properties of primary sludge, internal flow structures within PSTs and their impact on performance were investigated. This paper presents the results of full scale measurements, which also served as input data for the new edition of the German design guideline A 131 (DWA 2015). Also CFD investigations calibrated and validated based on full scale measurements are shown, which highlight some interesting details how geometry design affects PST performance.

Materials and methods

During the revision of the design guideline A 131 in the years 2013 and 2014 a measurement campaign was initiated among large wastewater treatment plant operators in order to estimate the performance of full scale PSTs. Within this measurement campaign the load of S_{COD}, X_{COD}, SS, N_{tot} and P_{tot} were determined in the influent and effluent of the full scale plants on the basis of flow proportional 24-h composite samples. For every single plant at least five dry weather days were included in the calculation of the performance indicators. Because on some of these plants also excess sludge or sludge water is usually added to the influent of the PST, provisions were taken that this flows were stopped during the course of the measurement.

The case study of the CFD investigation of one the four rectangular PSTs of the Graz Municipal Wastewater Treatment Plant (500 000 PE) shows a series of interesting details of geometry design of PSTs, especially the importance of inlet design and its impact on removal efficiency. The investigated tank at the Graz WWTP was one of the 32.50 m long, 7.00 m wide and 3.50 m deep PSTs. The CFD model was calibrated and validated against full-scale measurements.

Removal efficiency – Full scale results of PST performance

Considering the fluctuating results of the measurements on different large scale wastewater treatment plants (Fig. 1), the DWA-working group has clearly stated in the revision of the A 131 that for an optimal integration of the primary clarification in the whole wastewater treatment design process, measurements in order to determine the performance of PSTs should be mandatory. For this purpose it has been proposed that measurements should take place whenever possible. During such a measurement campaign flow proportional 24-hours composite samples in the influent und effluent should be analysed with respect to: COD, X_{COD}, SS, N_{tot} and P_{tot}.

The duration of such a measurement campaign should be longer than one week. By calculating the load in the influent and effluent of the PST, the elimination rate with regard to suspended solids elimination, the retention of particulate COD and the nutrients (N_{tot}, P_{tot}) can be easily assessed. Care has to be taken that no internal process streams, e.g. sludge water from the dewatering or excess sludge, are directed to the PST during the measurement campaign.

Only in design cases where no full scale results can be obtained, e.g. new plant or new PST, the design estimates should be used. These performance indicators provides estimates to calculate the elimination of total COD, particulate COD (X_{COD}), suspended solids (SS), total nitrogen (N_{tot}) and phosphorus (P_{tot}).

To assure that the function of the PST is not impaired at higher hydraulic loads, the minimum retention time at maximum hydraulic flow must exceed 20 minutes.

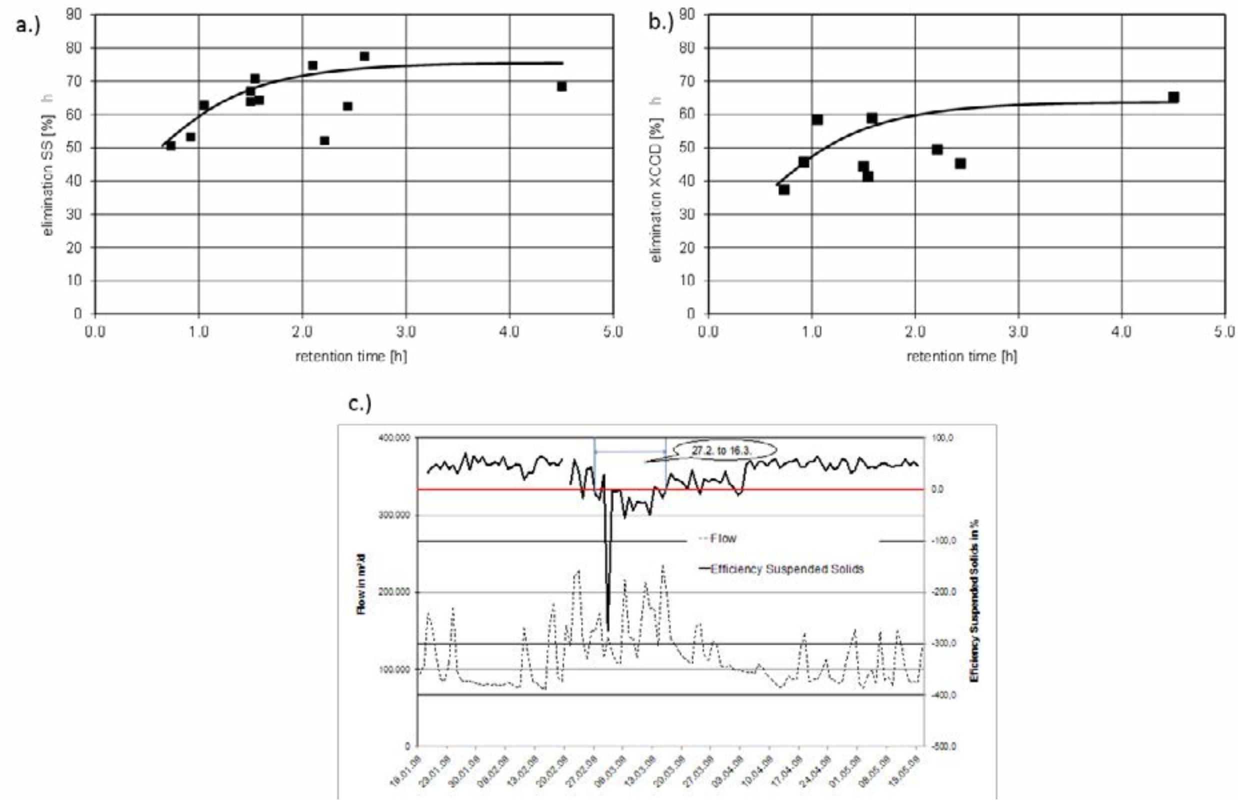

Figure 1 a.) Suspended solids elimination in PSTs on full scale plants; b.) Elimination of particulate COD in PSTs on full scale plants; c.) potential influence of stormwater inflow

The potential influence of stormwater inflow can be seen in Fig. 1 c. The retention time in the PST was between 1 and 2,5 hours. The duration of this event exceeded the sludge age of the biology and had a significant influence on the production of excess sludge production.

Geometry design and construstion

Similarly to secondary settling tanks the minimalization of kinetic and potential energy of inflowing jet is crucial to avoid high vertical velocity components, turbulences and dead zones.

PSTs show some basic differences in their hydrodynamic behaviour compared to secondary settling taks. Due to the higher range of surface overflow rates (hydraulic load), higher mean velocities and much lower SS concetrations entering the tank (while SSTs receive 3000 – 7000 mg/l of suspended solids, PST "only" 300 – 500 mg/l), density effects (density currents, density waterfall) do not affect PST behaviour considerably.

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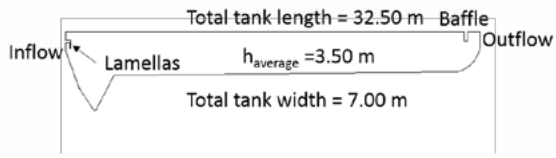
<tr><td rowspan="2">Type „I." original</td><td colspan="4">
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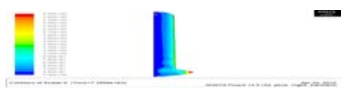
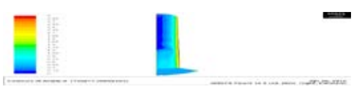
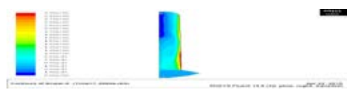
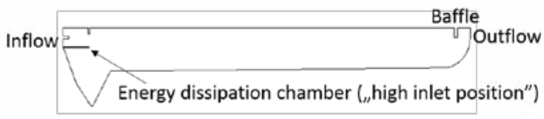
<tr><td>SS [g/l]</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Type „II."</td><td colspan="4">
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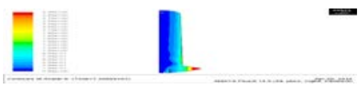
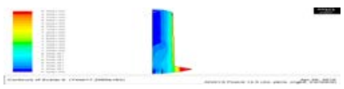
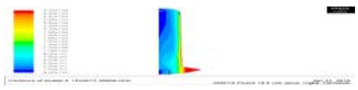
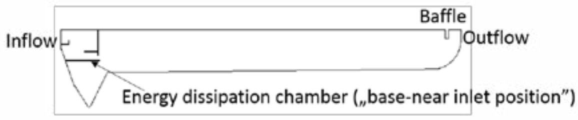
<tr><td>SS [g/l]</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Type „III."</td><td colspan="4">
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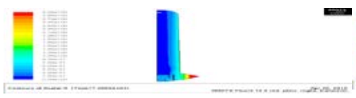
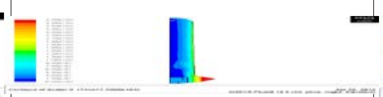
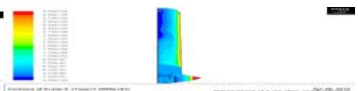
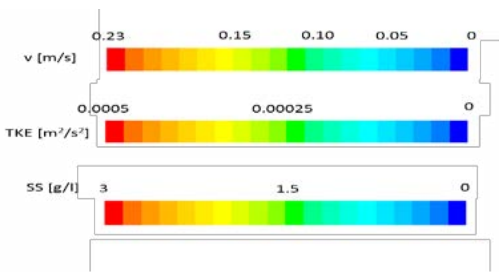
<tr><td>SS [g/l]</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">
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Table 1: Influence on inlet geometry onflow, turbulence and concentration pattern and PST efficiency v [m/s] is velocity, TKE [m²/s²] is turbulent kinetic energy and SS [g/l] is suspended solids concentration)

The simulation results (Table 1 and Fig. 2) show, that the impact of the inlet geometry design becomes particularly relevant at surface overflow rates above 5 m/h, which is the upper design limit for dry weather conditions according to the German design guidlines ATV 2000 and DWA 2015 (Table 2 and Fig. 2).

At lower surface overflow rates than 5 m/h the inlet design does not affect PST performance considerably. There is no big difference in the performance of the investigated PST caused by different design of inlet geeometry (type "I"-original, type "II" and type "III"). The results in Fig. 2 show also the same pattern. The deviation of the average values of the velocity magnitude (v[m/s]), the turbulent kinetic energy (TKE [m^2/s^2]), the effluent suspended solids concentration SS [g/l] and the SS removal efficiency [-]are negligible at 5 m/h.

However at high hydraulic loads (q_A = 8 and 10 m/h – wet weather conditions) the inlet geometry strongly influences PST efficiency. Slight subtleties in design lead to considerable differences in flow (mean velocities and the turbulent kinetic energy) and concentration pattern within the PST (Table 1). This results in huge deviations in PST performance regarding SS removal efficiency. At a surface overflow rate of 10 m/h deviations even up to 30% (0.3) could be observed in the CFD investigations (Fig. 2 d).

For example at high surface overflow rates (Table 1). Type "I" – original inlet construction, column 2 (8 m/h) and column 3 (10 m/h) the investigated PST shows an unfavourable pattern. The inlet jet plunges with considerable downward momentum component facilitated by lamellas positioned outside the inlet facility directly in the settling zone. The flow pattern is strongly affected by high velocity components and a high rate of turbulent kinetic energy induced by the inlet construction (too low hydraulic retention time, lamellas). This clearly shows that the inlet jet's kinetic and potential energy has to be satisfyingly dissipated within the inlet facility, which requires a design strongly based on hydrodynamic principles (satisfying volume and hydraulic retention time as well as optimal geometry design).

Some slight modifications of the inlet geometry like installing an " energy dissipatiung box" and shifting the inlet into a "base-near" or into a "high" position have a large influence on PST behavior and performance.

Therefore especially in the design of high loaded PSTs (retention times less, than 0.5 - 0.75 h and higher surface overflow rates than 5 m/h) CFD investigations are recommended.

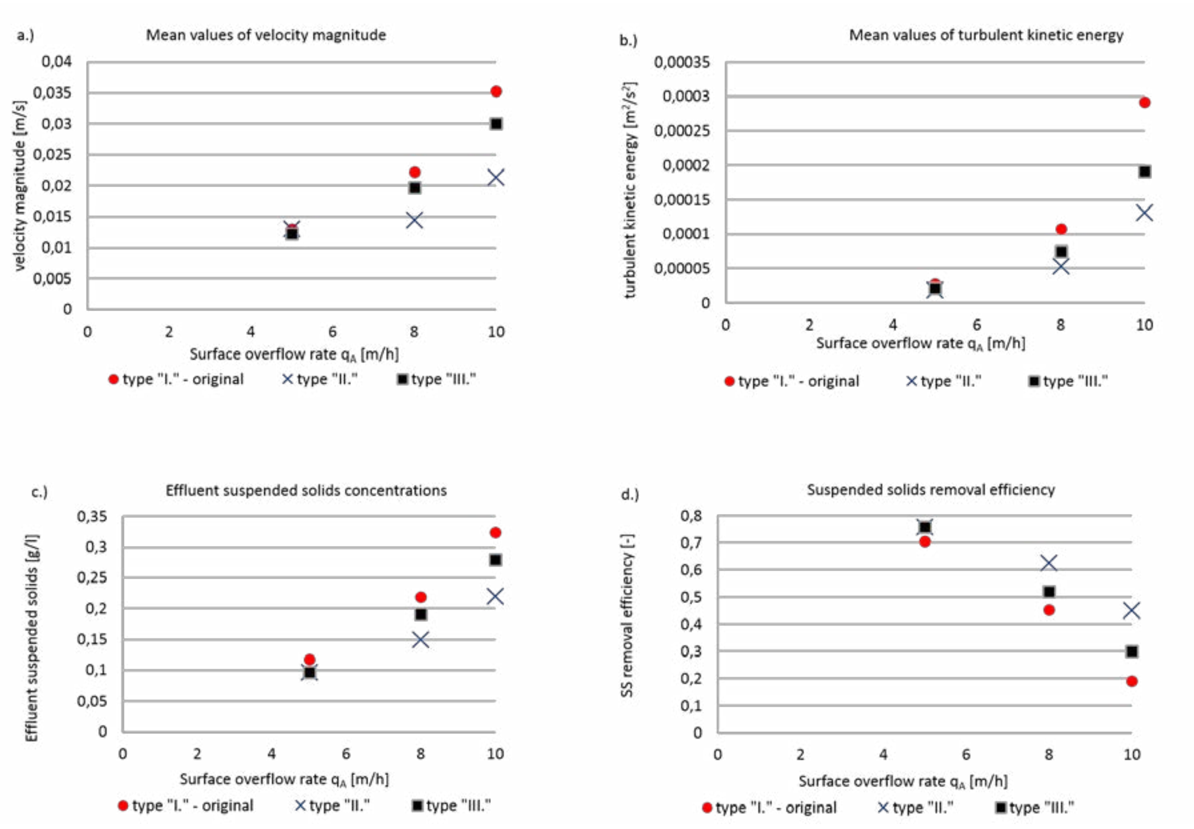

Figure 2: Average values of velocity magnitude (v [m/s]), turbulent kinetic energy (TKE [m^2/s^2]) effluent suspended solids concentration SS [g/l] and SS removal efficiency [-] at different surfance overflow rates (5, 8 and 10 m/h) and different inlet geometry design

Conclusions

In the last decades function and operation of PSTs has become complex including the control of readily biodegradable carbon (RBCOD) between denitrification and biogas production. PSTs have become integral part of biological wastewater treatment and energetics of large municipal WWTPs.

Strongly focusing on process oriented analysis, design and operation of PSTs, over the previous few years (2013, 2014 and 2015) at a huge number of PSTs "in situ" full scale measurements were carried out. Removal efficiency, settling properties of primary sludge, internal flow structures within PSTs and their impact on performance were ivestigated.

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